23 JANUARY 2002 REVISION; ACCEPTED BY APJ LETTERS
Preprint typeset using LaTeX style emulateapj v. 19/02/01

FIRST 0747+2739: A FIRST/2MASS QUASAR WITH AN OVERABUNDANCE OF C IV ABSORPTION SYSTEMS

GORDON T. RICHARDS[1], MICHAEL D. GREGG[2], ROBERT H. BECKER[2], AND RICHARD L. WHITE[3]
23 January 2002 Revision; Accepted by ApJ Letters

ABSTRACT

We present a Keck ESI spectrum of FIRST 074711.2+273904, a $K = 15.4$ quasar with redshift 4.11 that is detected by both FIRST and 2MASS. The spectrum contains at least 14 independent C IV absorption systems longward of the Lyα forest. These systems are found over a path length of $\Delta z = 0.984$, constituting one of the highest densities per unit redshift of C IV absorption ever observed. One of the C IV systems is trough-like and resembles a weak BAL-type outflow. Two of the C IV are "associated" absorption systems with $|v| < 3000\,\mathrm{km\,s^{-1}}$. Of the 11 remaining systems with $v > 3000\,\mathrm{km\,s^{-1}}$, eight are either resolved or require multiple discrete systems to fit the line profiles. In addition to C IV absorption, there are two low-ionization Mg II absorption systems along with two damped Lyα systems, at least one of which may be a C IV system. The overdensity of C IV absorption spans a redshift range of $\Delta z \sim 1$. Superclusters along the line of sight are unlikely to cause an overdensity stretching over such a long redshift path, thus the absorption may be an example of narrow, high-velocity, intrinsic absorption that originates from the quasar. We suggest that this quasar is a member of a transitional class of BAL quasars where we are just barely seeing the spatial, density, or temporal edge of the BAL-producing region (or period); the multiple high-velocity absorption systems may be the remnants (or precursors) of a stronger BAL outflow. If correct, then some simpler absorption line complexes in other quasars may also be due to outflowing rather than intervening material.

Subject headings: quasars: absorption lines — quasars: individual (FIRST J074711.2+273904)

1. INTRODUCTION

It is generally agreed that the broad absorption line (BAL) systems seen in the spectra of many quasars are intrinsic to the quasar, arising from high velocity outflow of gas directly from the accretion disk region (Weymann et al. 1991). Narrow absorption lines in quasar spectra, however, arise from a variety of sources. Narrow absorption lines with small velocities relative to the quasar emission redshift could be caused by galaxies along the line of sight, clouds in the interstellar medium of the host galaxy, or even smaller scale gas flows within a few parsecs of the black hole. On the other hand, most of the narrow absorption systems that have large velocities with respect to the emission redshift of the quasar are thought to be intervening (Sargent et al. 1988); however, there is increasing evidence that even some fraction of these may be intrinsic. In many BAL quasars, the absorption troughs have considerable structure, suggesting a connection to narrow absorption line systems. We discuss the spectrum of a newly discovered quasar, FIRST J074711.2+273904 (hereafter FIRST 0747+2739), with an overdensity of C IV absorbers in its spectrum. It may be an example of an object whose BAL component has been caught in a transitional state that could be related to orientation, time, or density.

2. DATA

FIRST 0747+2739 was discovered in the early stages of an ongoing project to search for extremely red quasars (Gregg et al. 2002). Candidates are found by matching point sources from the The 2-Micron All-Sky Survey (2MASS; Kleinmann et al. 1994) with FIRST radio sources, and then further matching to an optical catalog such as the APM (McMahon & Irwin 1992). This object also has been discovered independently by Benn et al. (2002). FIRST 0747+2739 has $R-K = 2.5$, not particularly red, but it is undetected on the blue Palomar sky survey plate, yielding $B-K \gtrsim 7$. The initial spectrum was obtained using the Kast spectrograph on the Lick Observatory 3m telescope. A higher signal-to-noise spectrum was obtained at Keck Observatory using the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995), revealing a strikingly rich system of absorption lines redward of Lyα.

FIRST 0747+2739 is located at $07^{\rm h}47^{\rm m}11^{\rm s}.208 + 27^\circ39'04''.00$ (J2000). There is a 2MASS source within $1''$ with J, H, and K magnitudes of 16.77, 16.16, and 15.38, respectively. The peak 20 cm flux density as measured by FIRST (Becker et al. 1995) is 1.08 ± 0.14 mJy; the integrated FIRST flux density is 1.55 mJy.

Motivated by the LRIS spectrum, we obtained a high-dispersion spectrum of FIRST 0747+2739 using the echelle spectrograph and imager (ESI; Epps & Miller 1998) on the Keck II telescope on the night of 2000 April 6. The night was photometric with $0''.9$ seeing. A 900s high-resolution spectrum was taken through a $1''.0$ slit in the echellette mode of ESI. In this mode, the spectral range of 3900 Å to 11000 Å is covered in 10 spectral orders with a nearly constant dispersion of $11.4\,\mathrm{km\,s^{-1}\,pixel^{-1}}$. The signal-to-noise of the spectrum ranges from 20 to 40 per pixel. Wavelength calibrations were performed with observations of a CuAr lamp. The spectrophotometric standard G191-B2B (Massey et al. 1988; Massey & Gronwall 1990) was ob-

[1] Department of Astronomy and Astrophysics, The Pennsylvania State University, University Park, PA 16802; gtr@astro.psu.edu
[2] UC-Davis and IGPP/LLNL, L-413, 7000 East Ave., Livermore, CA 94550; gregg,bob@igpp.ucllnl.org
[3] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218; rlw@stsci.edu

served for flux calibration. All observations were carried out at the parallactic angle. The data were reduced using a tailored set of IRAF and IDL routines developed by us specifically for ESI data.

3. ANALYSIS AND DISCUSSION

The overdensity of absorption features in the spectrum of FIRST 0747+2739 is immediately apparent in the Keck ESI data (Figure 1). Also conspicuous are a weak trough-like feature near 7815 Å and two damped Lyα systems. The region longward of Lyα emission is plotted on an expanded scale in the lower panels of Figure 1. We used an automated routine to search this spectral region for absorption lines with significance greater than 10σ. A total of 42 absorption line systems were identified, 34 being C IV doublets, including a BAL-like C IV trough. The systems are given in Table 1, which lists the system identification code, the redshift, the rest equivalent width of the blue and red components of the C IV doublet (if detected), the "ejection" velocity of the system, and other absorption species belonging to each system. The velocities are with respect to the quasar redshift and are given by $v = (R^2 - 1)/(R^2 + 1)$, where $R = (1 + z_{em})/(1 + z_{abs})$. The individual systems are merged into 18 "Poisson" systems (14 of which are C IV) by combining absorbers within $1000\,\mathrm{km\,s^{-1}}$ (Sargent et al. 1988).

3.1. *Line Densities*

How unusual is the abundance of C IV absorbers seen towards FIRST 0747+2739? At high-redshift, Steidel (1990) found that (based on 11 quasars) the expected number of C IV absorbers per unit redshift is approximately 1.0 ± 0.5 at $z \sim 3.25$ for rest equivalent width larger than 0.15 Å and $\beta c > 5000\,\mathrm{km\,s^{-1}}$. If we sum the equivalent widths of the each of the C IV systems within $150\,\mathrm{km\,s^{-1}}$, and ignore those three systems with $\beta c < 5000\,\mathrm{km\,s^{-1}}$, we find seven combined systems with rest equivalent widths larger than 0.15 Å for both lines in the C IV doublet. The path length searched for C IV between Lyα emission and C IV emission is $\Delta z = 0.984$. Thus, dN/dz is 7.11 for this line of sight — an excess of 12 standard deviations from the Steidel (1990) measurement.

For weak C IV lines, Tripp et al. (1996) find $dN/dz = 7.1 \pm 1.7$ for $W_r > 0.03$ Å and $1.5 < z < 2.9$ (based on four quasars). If we impose constraints on the Tripp et al. (1996) data to match our more conservative 10σ significance limit and combine systems within $200\,\mathrm{km\,s^{-1}}$, then the density reported by Tripp et al. (1996) is reduced to $dN/dz = 3.75 \pm 1.25$. In our Keck ESI spectrum of FIRST 0747+2739 we find, using the same criteria, at least 9 distinct high-velocity C IV systems. Over the path length observed, that yields $dN/dz = 9.1 \pm 3.0$, which is a 4.3σ excess as compared to Tripp et al. (1996); thus there is evidence that the overdensity of absorption may extend to weaker systems.

Since Sargent et al. (1988) and Steidel (1990) found that the density of absorption lines decreases with increasing redshift (for strong lines) and since the C IV absorption systems found in FIRST 0747+2739 are at higher redshifts than either the Tripp et al. (1996) or Steidel (1990) samples, our observed density of lines may be even more significant.

What can explain the large overdensity of absorption toward FIRST 0747+2739? All possible explanations can be classified as intervening or intrinsic. In the intervening case, the absorption lines arise from material associated with galaxies along the line of sight that have no relation to the quasar. In the intrinsic case, the absorption is caused by high velocity ejecta from the quasar itself.

3.2. *The Intervening Hypothesis*

The number density of strong C IV lines towards this quasar is much larger than is normally observed. An examination of the spectra and tables from Sargent et al. (1988) and Steidel (1990) along with a query of the York et al. (1991) catalog of quasar absorption lines reveals that such a concentration of C IV absorption over such a long path length is extremely rare. None of the 11 high-redshift quasars from Steidel (1990) has a density of C IV absorption higher than FIRST 0747+2739. Two of the 55 lower redshift quasars from Sargent et al. (1988) do have absorption line densities higher then FIRST 0747+2739; Q0013-004 (UM 224; $z = 2.086$) and Q0854+191 ($z = 1.896$) have six and seven strong ($W_r > 0.15$ Å) "Poisson" systems over path lengths of $\Delta z \sim 0.6$, respectively.

Quasars that have relatively high densities of absorption have created much interest in the search for signs of superclustering at high redshift (e.g., Heisler et al. 1989; Romani et al. 1991; Foltz et al. 1993; Dinshaw & Impey 1996). However, most of these quasars have absorption systems where the overdensity is very limited in its redshift range, such as CSO 118 (Ganguly et al. 2001) and the well-studied PKS 0237−233 (Foltz et al. 1993). FIRST 074711.2+273904 is different in the sense that the overdensity of C IV absorption is spread over a large redshift range ($\Delta z \sim 1$) — much too large to be explained by a single supercluster. A search of the NASA Extragalactic Database (NED) to look for other quasars to test the superclustering hypothesis found no other known quasars within 30 arcminutes, although there are five other radio sources within 10′ of FIRST 0747+2739.

One possible way to reconcile the intervening hypothesis with the absorption line overdensity in FIRST 0747+2739 is if the quasar is being gravitationally magnified by the intervening material. Such magnification could occur without producing multiple images, and might help to explain why a quasar with $z > 4$ is so bright. The possibility of compound microlensing of quasars by their absorption line systems is not a new concept (Thomas et al. 1995; Vanden Berk et al. 1996). This object, however, is a point source in our NIRC K-band image from Keck Observatory, obtained in $0\farcs4$ seeing.

Finally, it is possible that the apparent overdensity of absorption systems in FIRST 0747+2739 is either just chance coincidence, or is not actually all that uncommon. The number of high-redshift quasars that are well-studied for absorption is still quite small and additional investigations may yet turn up more cases like FIRST 0747+2739. Such a finding would not necessarily be evidence for either the intrinsic or the intervening hypothesis, however. For now, we conclude that the nature of FIRST 0747+2739 is highly unusual and next to impossible to reconcile with any picture where a significant number of the absorbing systems can be attributed to intervening objects unasso-

ciated with the quasar.

3.3. *The Intrinsic Hypothesis*

Strong circumstantial evidence to support the intrinsic interpretation for the plethora of narrow, high-velocity absorption systems in FIRST 0747+2739 is the presence of similar, almost certainly intrinsic, absorption at low velocities relative to the quasar emission line frame. System S is typical of intrinsic absorption line systems seen in other quasars, exhibiting N V absorption and a small blueshift relative to the quasar's C IV emission redshift. System Q appears to be a weak BAL-like outflow; System P is also broad, but the blue and red components of the troughs are resolved. Finally, System R, with a velocity of only +1600 km s^{-1}, may also be an intrinsic absorption system.

There is ample evidence in the literature for the intrinsic interpretation of high-velocity non-BAL outflows in quasars. Jannuzi et al. (1996) and Hamann et al. (1997a) found weak, high-velocity, trough-like outflows; Hamann et al. (1997a) showed that the outflows in Q 2345+125 are intrinsic because the absorption profiles varied in ~ 3.5 months in the quasar rest frame. Richards (2001) and Richards et al. (2001) give statistical evidence that some narrow, high-velocity C IV absorption line systems may be intrinsic in nature. Finally, Ganguly et al. (2001) discuss an overdensity of C IV absorption in CSO 118.

FIRST 0747+2739 is similar to one of the quasars that comprise the so-called "Tololo Pair" (e.g., Dinshaw & Impey 1996), namely Tol 1038−2712, which also has weak BAL-like troughs. This well-studied pair is a favorite for superclustering studies (e.g., Jakobsen et al. 1986) since the two quasars appear to have common absorption line systems despite the rather large ($17'.9$) separation between the quasars. Other authors (e.g., Cristiani et al. 1987; Robertson 1987) still favor the hypothesis that both are BALQSOs and the absorption is from intrinsic high velocity outflow. The velocity separation of the lines in the Tololo Pair is reminiscent of the of the double-trough BAL structure found by Korista et al. (1993) for BALQSOs in general, lending credence to the idea that the absorption lines in the Tololo pair are intrinsic. In any case, the similarity of Tol 1038−2712 and FIRST 0747+2739 may help lead to an understanding of the nature of the absorption in both systems.

Q1303+308 provides another interesting comparison; because of its complex absorption structure, it has been classified as a BALQSO (Foltz et al. 1987); however, the absorption lines are all very narrow and do not meet the traditional BAL criteria set forth largely by the same authors a few years later (Weymann et al. 1991). One must then wonder, how we would classify an object with a slightly lower incidence of absorption than Q1303+308. Such an object might simply be classified as a quasar with an overdensity of absorption line systems much like FIRST 0747+2739.

The fashionable method of determining whether a particular absorption system is intrinsic is either to determine the "coverage fraction" of the quasar or to show that the absorption line system is variable (Barlow et al. 1997; Hamann et al. 1997b). Lacking the data to test for variability, we have analyzed the coverage fractions for each of our systems as a function of velocity. Many of the high-velocity systems do indeed have coverage fractions that are consistent with the intrinsic hypothesis; however, the majority of the systems are resolved into multiple components or blended, which means that the coverage fraction results are not entirely reliable. Thus, on the basis of our covering fraction analysis alone, we are not able to confirm (or exclude) the possibility that the overdensity of absorption lines in this quasar spectrum is due to intrinsic absorption.

Regardless of the lack of conclusive evidence from variability or coverage fractions, the presence of trough-like absorption at moderate velocities and the large redshift span of the overdensity of the C IV absorption points towards an intrinsic origin of at least some of the relatively narrow, high-velocity C IV absorption systems. We suggest that FIRST 0747+2739 is a quasar in transition from (to) a quasi-BAL object to (from) a standard quasar. The lack of strong, broad absorption can be explained as being the result of one or more effects. As time goes on, it may be natural for the lines to become narrow as the clouds dissipate down to their small, dense cores; or BAL features might be a superposition of many narrow features and FIRST 0747+2739 has a relatively low density of them; or perhaps the many narrow absorbers can somehow be attributed to orientation effects.

4. CONCLUSIONS

In summary, we find that that overdensity of C IV absorption lines seen along the line of sight to FIRST 0747+2739 is sufficiently high that it is likely that at least some of these systems are high-velocity, intrinsic absorption systems. The presence of weak trough-like absorption features suggests that FIRST 0747+2739 may be a transitional BAL quasar that is being observed at a brief phase in its transition to (or from) a standard quasar, or is being viewed at a highly specific orientation, or that it is a BAL with a very low absorber density. If the absorption is intrinsic, monitoring with high resolution spectroscopy over the course of $\gtrsim 18$ months may reveal variability of the absorbers, a signature of intrinsic absorption. Confirmation (or exclusion) of the intrinsic hypothesis for the unusually large number of high-velocity C IV systems in FIRST 0747+2739 would have interesting consequences for C IV absorption line studies, particularly high-redshift superclustering studies.

GTR acknowledges support from NSF grant AST99-00703. RHB and MDG acknowledge support from the NSF (grants AST-98-02791 and AST-98-02732) and the Institute of Geophysics and Planetary Physics (operated under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48). This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We thank Rajib Ganguly and Jane Charlton for useful discussions.

REFERENCES

Barlow, T. A., Hamann, F., & Sargent, W. L. W. 1997, in ASP Conf. Ser. 128: Mass Ejection from Active Galactic Nuclei, 13
Becker, R. H., White, R. L., & Helfand, D. J. 1995, ApJ, 450, 559
Benn, C. R., Vigotti, M., Pedani, M., Holt, J., Mack, K.-H., Curran, R., & Sánchez, S. F. 2002, MNRAS, 329, 221
Cristiani, S., Danziger, I. J., & Shaver, P. A. 1987, MNRAS, 227, 639
Dinshaw, N. & Impey, C. D. 1996, ApJ, 458, 73
Epps, H. W. & Miller, J. S. 1998, Proc. SPIE, 3355, 48
Foltz, C. B., Hewett, P. C., Chaffee, F. H., & Hogan, C. J. 1993, AJ, 105, 22
Foltz, C. B., Weymann, R. J., Morris, S. L., & Turnshek, D. A. 1987, ApJ, 317, 450
Ganguly, R., Charlton, J. C., & Bond, N. A. 2001, ApJ, 553, L101
Gregg, M. D., et al. 2002, ApJ, in press, astroph/0107441
Hamann, F., Barlow, T., Cohen, R. D., Junkkarinen, V., & Burbidge, E. M. 1997a, in ASP Conf. Ser. 128: Mass Ejection from AGN, 19
Hamann, F., Barlow, T. A., Junkkarinen, V., & Burbidge, E. M. 1997b, ApJ, 478, 80
Heisler, J., Hogan, C. J., & White, S. D. M. 1989, ApJ, 347, 52
Jakobsen, P., Perryman, M. A. C., Ulrich, M. H., Macchetto, F., & di Serego Alighieri, S. 1986, ApJ, 303, L27
Jannuzi, B. T., et al. 1996, ApJ, 470, L11
Kleinmann, S. G., et al. 1994, Ap&SS, 217, 11
Korista, K. T., Voit, G. M., Morris, S. L., & Weymann, R. J. 1993, ApJS, 88, 357
Massey, P. & Gronwall, C. 1990, ApJ, 358, 344
Massey, P., Strobel, K., Barnes, J. V., & Anderson, E. 1988, ApJ, 328, 315
McMahon, R. G. & Irwin, M. J. 1992, in ASSL Vol. 174: Digitised Pptical Sky Surveys, 417
Oke, J. B., et al. 1995, PASP, 107, 375
Richards, G. T. 2001, ApJS, 133, 53
Richards, G. T., Laurent-Muehleisen, S. A., Becker, R. H., & York, D. G. 2001, ApJ, 547, 635
Robertson, J. G. 1987, MNRAS, 227, 653
Romani, R. W., Filippenko, A. V., & Steidel, C. C. 1991, PASP, 103, 154
Sargent, W. L. W., Steidel, C. C., & Boksenberg, A. 1988, ApJS, 68, 539
Steidel, C. C. 1990, ApJS, 72, 1
Thomas, P. A., Webster, R. L., & Drinkwater, M. J. 1995, MNRAS, 273, 1069
Tripp, T. M., Lu, L., & Savage, B. D. 1996, ApJS, 102, 239
Vanden Berk, D. E., Quashnock, J. M., York, D. G., & Yanny, B. 1996, ApJ, 469, 78
Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23
York, D. G., Yanny, B., Crotts, A., Carilli, C., Garrison, E., & Matheson, L. 1991, MNRAS, 250, 24

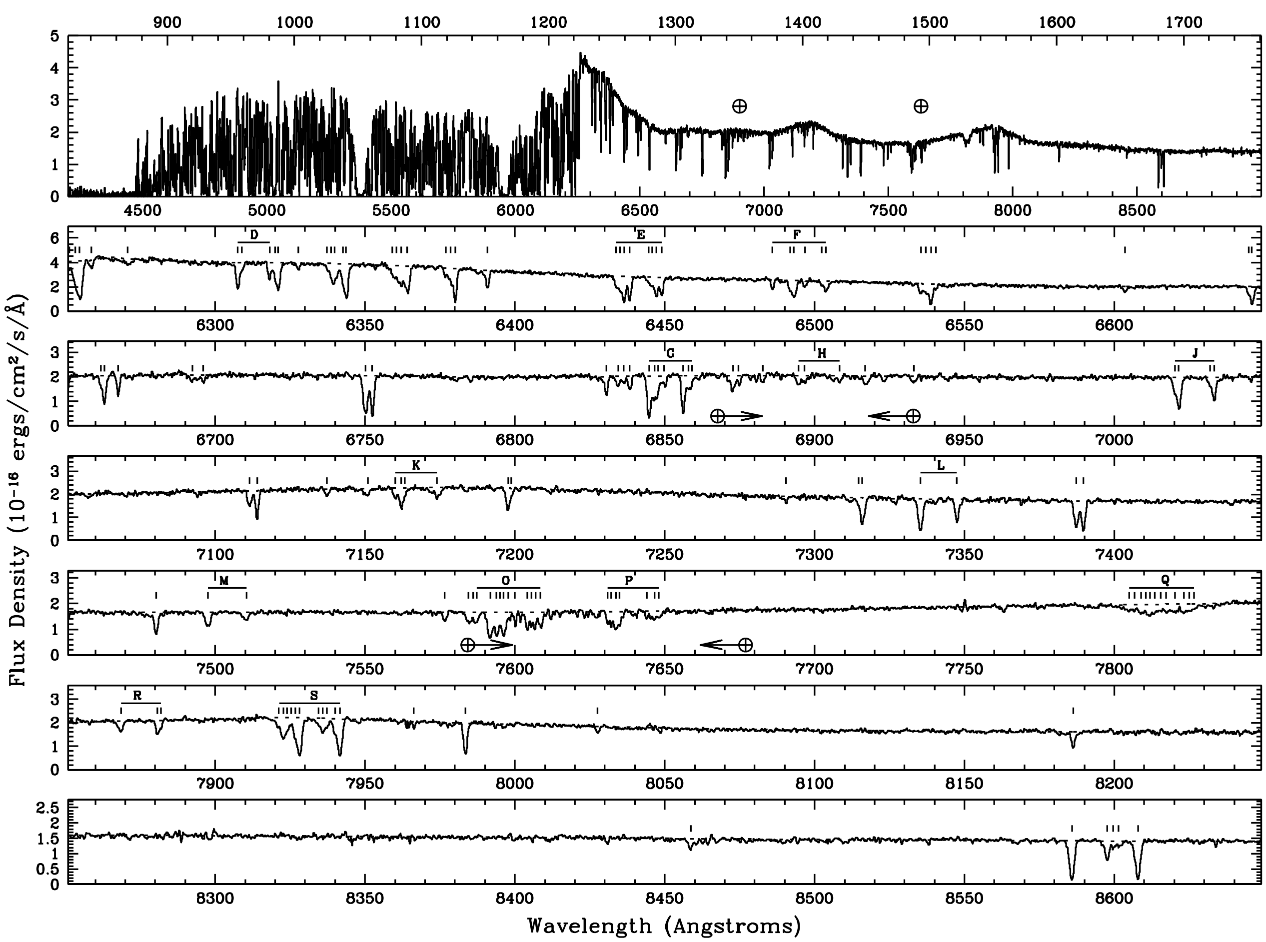

FIG. 1.— (*Top*) The FIRST 0747+2739 ESI spectrum from 4000 Å to 9000 Å, smoothed by 9 pixels; the top axis gives the rest frame wavelengths. Note the weak trough just blueward of the C IV emission line. Regions that may be affected by the O_2 A and B telluric absorption bands are labeled. However, the absorption in these regions is probably real since the spectrum of another quasar taken on the same night showed no residual absorption after telluric correction. (*Bottom Six Panels*) An expanded view of the spectrum longward of Lyα at the full 11.4 km s^{-1} pixel^{-1} resolution. The 14 C IV systems are labeled; a horizontal line connects the wavelength of the lowest redshift $\lambda\,1548$ to the highest redshift $\lambda\,1551$ line.

Table 1
Absorption Systems

Sys.	z	C IV W_r 1548	C IV W_r 1551	Vel. (km/s)	Other Lines
A1a	1.3762[a]			193330	Mg II
A1b	1.3766			193300	Mg II,Mg I
A2	1.3783			193170	Mg II,Mg I
B	2.0704			140840	Mg II,Mg I,Fe II 2344, 2374,2383,2587,2600
C	2.6083[b]			100370	Fe II 2344,2374,2383
D	3.0741	0.18	0.11	66830	
E1a	3.1556[a]	0.09	0.05	61150	
E1b	3.1565[a]	0.14	0.08	61090	
E1c	3.1574	0.24	0.18	61030	
E2	3.1585	0.22	0.17	60950	
F1	3.1893	0.09	0.06	58830	
F2	3.1939[c]	0.21	0.12	58510	
G1	3.4212	0.28	0.24	43140	DLA,Si II,Fe II,Al II
G2	3.4222	0.15	0.08	43070	DLA
G3	3.4231	0.09	0.04	43020	DLA,Si II,Fe II,Al II
H1	3.4534[d]	0.06	0.03	41000	
H2	3.4546[d]	0.04	0.04	40920	
Ja	3.5344[a]	0.10	0.05	35680	Si IV?,Al II?
Jb	3.5353	0.21	0.14	35620	Si IV?,Al II?
K1	3.6248[d]	0.06	0.03	29830	
K2a	3.6260	0.11	0.06	29750	
K2b	3.6268[a]	0.04	0.03	29700	
L	3.7380	0.24	0.15	22630	
M	3.8428	0.11	0.05	16100	
N1	3.8972[a]			12750	DLA,O I,Si II,[e] C II, Fe II,Al II
N2	3.8985[a]			12670	DLA,O I,Si II,[e] C II, Fe II,Al II
N3	3.8996	?	?	12610	DLA,O I,Si II,[e] C II, Fe II,Al II,Si IV?
O1	3.9008[f]	0.06	0.07	12530	Si IV
O2	3.9036[f]	0.20	0.11	12360	Si IV
O3	3.9050[f]	0.14	0.10	12280	Si IV
O4	3.9065[f]	0.15	0.11	12190	Si IV
P1	3.9289[g]	0.06	0.04	10820	
P2	3.9297[g]	0.08	0.03	10770	
P3	3.9306[g]	0.11	0.05	10720	
P4	3.9315[g]	0.08	0.04	10660	
Q	4.0449[h]	BAL?	BAL?	3850	
R	4.0825	0.06	0.03	1620	
S1a	4.1164[a]	0.05	0.04	-380	N V
S1b	4.1174	0.11	0.07	-430	N V
S1c	4.1182[a]	0.07	0.05	-480	N V
S2a	4.1200[a]	0.11	0.09	-590	N V
S2b	4.1208	0.23	0.22	-630	N V

Note. — Systems are combined within $1000\,\mathrm{km\,s^{-1}}$. The letter "I" is skipped to avoid confusion. Major subsystems (distinct minima) are indicated by 1, 2, 3, 4 after the system letter. Minor subsystems (needed to explain the line profile) are indicated by a, b, c. Unless otherwise indicated, the absorption line systems are damped Lyα (DLA); Mg II $\lambda\lambda$ 2796, 2804; Mg I λ 2853; Al II λ 1671; O I λ 1602; C II λ 1335; Fe II λ 1608; Si II λ 1527; Si IV $\lambda\lambda$ 1393, 1402; and N V $\lambda\lambda$ 1238, 1242.

[a] Weaker system. Needed to explain profile of stronger system.

[b] Based on Fe II. Mg II is beyond the wavelength range studied.

[c] Line profile is resolved at this resolution.

[d] Questionable system.

[e] Also Si II λ 1304.

[f] Heavily blended.

[g] Heavily blended, trough-like.

[h] Too blended and trough-like to resolve into components.